IRRIGATION WITH SEWAGE EFFLUENT:
Nutrient Inputs and Its Effect on Crop Quality

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Although the disposal of sewage effluent in the form of irrigation on crops has been practiced in many countries of the world for centuries, it has only recently received much attention and investigation in the semiarid prairie climate. The benefits associated with applying sewage effluent on land in semiarid climates can be summarized in the following ways:

a) There should be increased plant growth from the application of water to the land and through the application of essential plant nutrients such as nitrogen and phosphorus. This in turn will increase the phosphorus and protein content of the forage with the resulting increase in digestible organic matter of the plant material.

b) In the soil, plant nutrients should contribute to the build-up of the soil nitrogen and phosphorus reserves and also possibly increase the availability of trace elements such as zinc and copper.

c) The extra organic matter added may improve structure and increase the percentage of carbon in the soil.

It is, therefore, not surprising that many smaller urban centres have started to use sewage effluent on bromegrass, on bromegrass plus alfalfa mixtures, and other forage crops. However, the composition of this sewage effluent changes markedly from community to community with the salt content of the well water available. Enough evidence has now accumulated, especially on the use of sewage effluent from industrial communities to note that the following hazards are possible (Cornforth, 1973; King and Morriss, 1972, 1973):

a) In plants growing in the soil, a nutrient in balance may occur and heavy metals may accumulate, which may affect the palatibility of the grass. In certain cases, when either excess nitrate N or heavy metals occur, the forage may be poisonous to stock.

b) Animal pathogens may survive and infect stock grazing the land.

c) There may be complaints from nearby residents of offensive odors.

d) The quality of the soil may suffer as the accumulation of plant nutrients may cause shallow rooting of crops, heavy metals accumulate causing a high concentration in the plants and the suppression of microbial activity in the soil. The organic matter may block drainage so that the structure is weakened and the soil is easily "poached" by cattle, and air permeability within the soil is decreased.

It becomes essential for any community which plans to start spreading sewage effluent on the land to examine each of these possible benefits or hazards with regard to the nutrient and salt concentrations of the sewage effluent applied.

In this particular study, sewage effluent from the city of Moose Jaw was used to irrigate bromegrass grown on soil columns collected from an Asquith soil from an area south of Moose Jaw and an Oxbow soil from north of Saskatoon. Full details of this study are described in the previous paper by Dr. de Jong and this paper will deal with the effect of sewage effluent irrigation on the quality of the herbage and the quality of the soil.

Four batches of sewage effluent were taken at various time intervals over the period of the experiment, and the variation in the composition of the sewage effluent as far as nitrogen, phosphorus, zinc, sulphate and boron, is shown in Table 1. It can be noted that

Table 1. Composition of sewage* effluent.

Season	1	3	5
	$\overline{X}$ S.E.	$\overline{X}$ S.E.	$\overline{X}$ S.E.
EC, mmhos/cm	2.21±0.02	2.30±0.02	2.04±0.01
pH	8.51±0.06	8.32±0.04	8.21±0.08
Min.-N, ppm	11.1 ±0.4	27.8 ±0.7	38.8 ±0.9
Org.-N, ppm	8.4 ±0.5	5.5 ±0.4	2.8 ±0.5
Org.-C, ppm	25 ±2	26 ±1	24 ±1
PO_4-P, ppm	2.0 ±0.2	4.5 ±0.1	6.2 ±0.2
Total P, ppm	2.8 ±0.2	3.9 ±0.1	5.7 ±0.3
Zn, ppm	0.04±0.01	0.01±0.00	0.00±0.00
SO_4-S, ppm	254 ±6	203 ±4	133 ±2
BO_4-B, ppm	0.79±0.02	1.03±0.04	0.81±0.01
Sod. Ads. Ratio	3.65	4.22	5.04

*Samples were put through a coarse filter prior to analysis. This had the effect of removing some C and P.
Ratio = $\frac{\text{Unfiltered}}{\text{Filtered}}$ for Org.-C = 1.50, Inorg.-C = 1.00, Total P = 1.25, and Org.-N = 2.0

although the pH remained around about 8.2 to 8.5, the composition of the mineral nitrogen was 11 ppm at one sampling and almost 39 ppm at another. Similarly, the phosphate concentration increased threefold from season 1 to season 5. It should be noted that in many of the determinations it was necessary to put the samples through a coarse filter and this retained small amounts of the phosphorus and carbon. But for comparative purposes, the figures were valid.

Selected properties of the soils used in the growth chamber experiment are shown in Table 2, and it will be noted that the initial level of nitrate nitrogen in the Asquith soil was extremely low, whereas the Oxbow contained more nitrogen with depth.

Table 2. Selected properties of the soils used in the growth chamber experiment on irrigation with sewage effluent.

	Soil Properties					
	Asquith LFS			Oxbow Loam		
$NaHCO_3$-extractable	0-15	15-30	30-60	0-15	15-30	30-60
	cm					
NO_3-N, ppm	3	1.5	1	4	10	8
H_2PO_4-P, ppm	12.5	5	2.5	7	2	0.5
K, ppm	393	195	113	286	180	92
pH	6.6	6.1	6.3	7.6	8.2	8.2

Fifty-four undisturbed soil cores at the Asquith and Oxbow sites were used in the study. The cores were subdivided into three groups of 18 cores each, each group of 18 cores was further subdivided into five treatments:

d - dryland, no irrigation, 2 columns
9" - effluent irrigation, 4 columns
18" - effluent irrigation, 4 columns
27" - effluent irrigation, 4 columns
36" - effluent irrigation, 4 columns

All nitrogen and phosphorus were supplied by the effluent irrigation with the exception that at the start of the experiment the Asquith soil received the equivalent of 81 kg of N/ha to bring it up to the same nitrogen level as the Oxbow soil and the Oxbow soil received 50 kg P/ha. The irrigation rates were approximately those noted above, although in some cases, these could not always be realized and the actual rates are given in Dr. de Jong's paper.

Fifteen bromegrass seedlings were transferred into each column and the irrigation treatment applied to the soil over a period of approximately 13 weeks. During the first season, the bromegrass was cut three times, while in the second, third, fourth and fifth seasons only two cuts were obtained.

The actual quantity of nitrogen and phosphorus supplied with season was substantial, and Tables 3, 4 and 5 show the actual total quantities of nitrogen, phosphorus and potassium applied (for convenience these figures are given in terms of kg/ha as they gave a more realistic idea of the rates applied).

Table 3. Total N added (kg N/ha) in the sewage effluent irrigation treatment (based on filtered sewage).

	Season					
Treatment	1		2	3	4	5
	Asquith	Oxbow	Both Soils			
H_2O	81	0	0	0	0	0
9"	145	64	59	84	109	97
18"	205	124	117	168	219	192
27"	252	171	176	252	325	299
36"	272	191	195	279	365	302

Initial NO_3-N to 24", Asquith - 19 kg N/ha and Oxbow - 100 kg N/ha.

Table 4. Total P added (kg P/ha) in the sewage effluent irrigation treatment (based on unfiltered sewage).

Treatment	Season					Total
	1	2	3	4	5	
H_2O	0	0	0	0	0	0
9"	2.7	3.8	5.0	10.1	8.2	30.7
18"	5.3	7.7	11.9	20.1	16.4	61.4
27"	7.4	11.5	17.9	30.2	24.6	91.5
36"	8.2	12.8	19.8	33.5	27.3	10.18

Table 5. Amount of potassium applied with various sewage effluent treatments to both soils (kg K/ha).

Treatment	Season				
	1	2	3	4	5
H_2O	0	0	0	0	0
9"	37.1	44.5	50.2	50.2	51.3
18"	74.1	88.9	99.8	99.8	103.2
27"	102.0	133.4	149.9	149.9	154.5
36"	148.2	148.2	166.4	166.4	172.1

The average plant yields in terms of g/column are given in Table 6. These data show that during the first

Table 6. The average plant yields obtained under different sewage irrigation treatments (average of reps: g d.m./column).

Treatment	Season		
	1	3	5
	Asquith Soil		
H_2O	3.31	0.87	0.61
9"	4.55	2.27	5.80
18"	5.68	5.16	12.02
27"	6.65	7.88	16.56
36"	6.12	9.54	16.34
	Oxbow Soil		
H_2O	3.64	0.61	1.57
9"	4.76	2.23	5.30
18"	5.82	5.21	11.37
27"	6.72	7.09	13.90
36"	6.81	8.66	16.85

season when the nitrogen content of the soil was equivalent to 100 kg N/ha, there was a linear relationship between the nitrogen applied and the yield obtained. However, by season 5 the slope of this curve (Fig. 1) was much steeper. This shows that there was a build-up in the readily mineralizable nitrogen in the soil and that the yield obtained in season 5 was due not only to the fresh nitrogen applied, but also to the mineralization of nitrogen from the previous season.

The results as depicted in Figure 1 are a combination of a nitrogen and water effect; as it can be shown in Fig. 2 the yield obtained was not related to water alone. Whereas in Fig. 1 the higher rates of applied nitrogen would automatically mean higher amounts of water applied at the same time.

Other studies on bromegrass in the semiarid prairie areas have shown that residual effects from nitrogen have been obtained in the first and second year, even though little or no available nitrogen was found in the soil in spring at the time growth was commencing (Ukrainetz, 1969).

Quality of Forage

In the review of forage crop fertilization on the eastern prairies, Ukrainetz (1969) stressed the fact that the application of nitrogen fertilizer would produce substantial increases of forage in the first year, and in subsequent years. However, he did show that when there were large quantities of available nitrogen in the soil either from mineralization of soil nitrogen or the application of nitrogen fertilizers, the nitrate content of grasses normally increases during the early growth stages and subsequently the levels decline as dry matter production increases more rapidly. The amounts which accumulated are related to such factors as the species of crop, climatic conditions, and rates and form of nitrogen applied. The levels of nitrate in forage crops that could be considered toxic to livestock have not been clearly established but would appear from the literature that levels above 0.14% nitrate-N can be considered potentially dangerous (Lawrence and Ashforth, 1968; Moline et al., 1974; Ukrainetz, 1969). In the present study, the percentage nitrogen in a plant dry matter was measured with season, as was percentage phosphorus, percentage potassium, and other elements such as boron which might contribute to a deterioration in the quality of the forage. As well as measuring total nitrogen in the plant dry matter, the nitrate nitrogen was determined over season. The results of these analyses are shown in Table 7, which show little difference in total nitrogen between season 1 and season 5, except of course in the treatments that received no sewage effluent where the percentage N declined. The percentage nitrogen in the plant dry matter in general did not increase but maintained approximately the same level and the maximum nitrate nitrogen in any season was well below the levels quoted by Ukrainetz (1969) as being possibly toxic to livestock.

With phosphorus (Table 8) the application of sewage effluent increased the quality of forage as the percentage

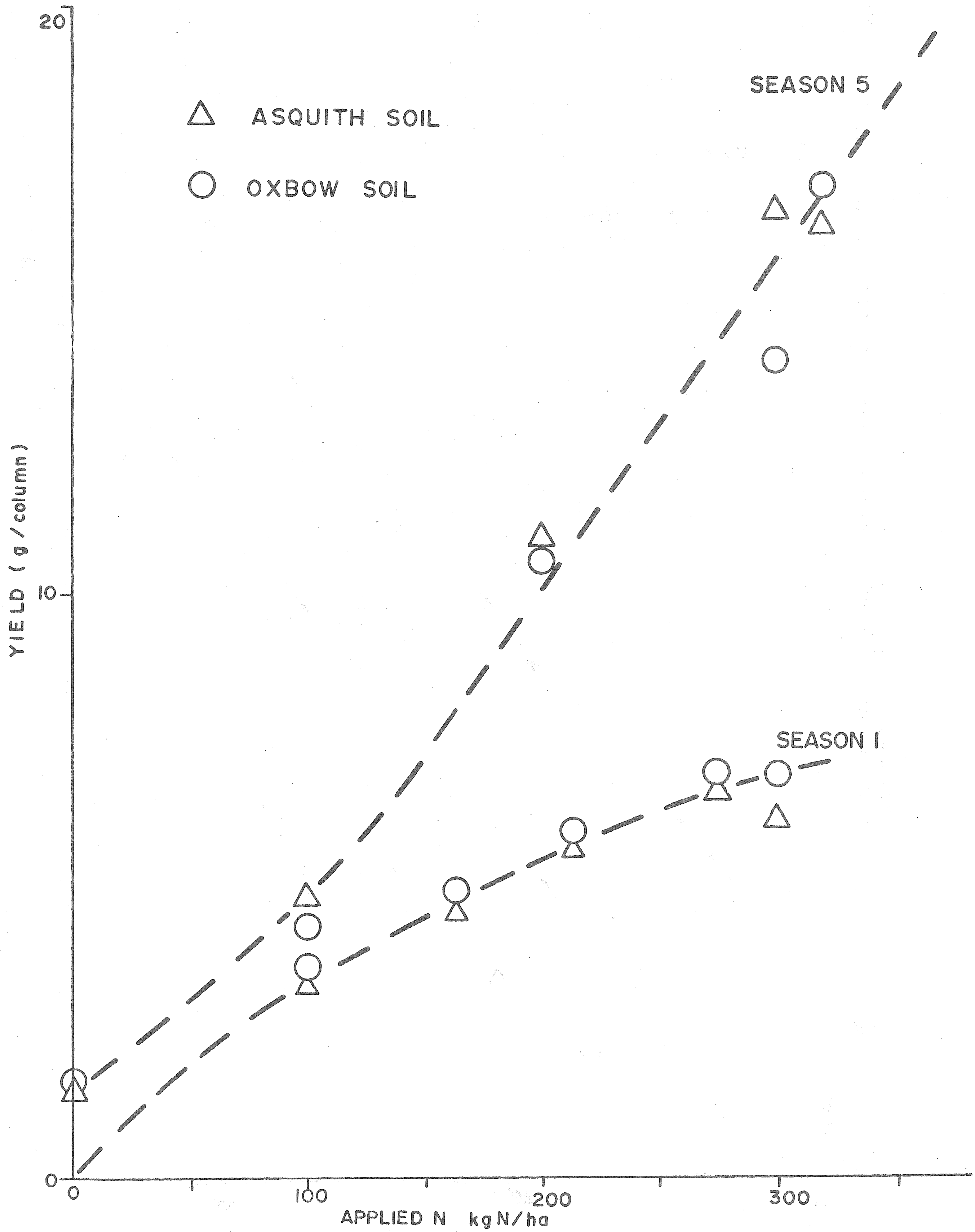

Fig. 1. The yield of bromegrass obtained with sewage effluent irrigation compared to the quantity of applied N in seasons 1 and 5.

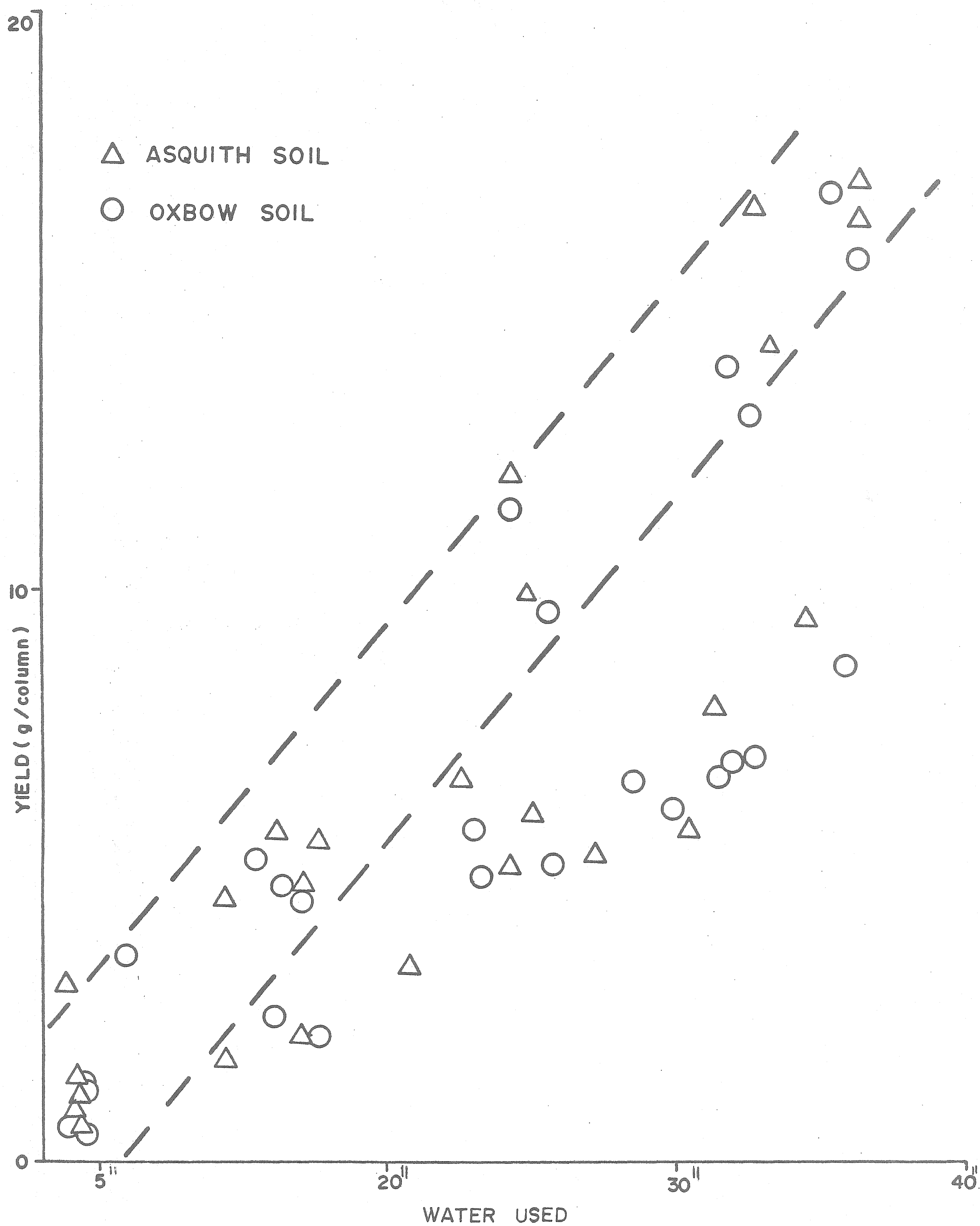

Fig. 2. The yield of bromegrass obtained compared to the quantity of water used (inches) over all seasons.

Table 7. Quality of forage: The percent N in plant dry matter grown under different sewage effluent irrigation treatments.

Treatment	Season 1*		Season 5**	
	Asquith	Oxbow	Asquith	Oxbow
H_2O	2.4	2.3	1.6	1.8
9"	2.0	2.3	1.8	2.0
18"	2.1	2.5	1.9	2.0
27"	2.2	2.4	2.1	2.2
36"	2.2	2.5	1.9	2.0

*Average of 2nd and 3rd cuts.
**Maximum NO_3-N in 5th season 0.0030%.

Table 8. Quality of forage: The percent P in plant dry matter grown under different sewage effluent irrigation treatments.

Treatment	Season 1		Season 5	
	Asquith	Oxbow	Asquith	Oxbow
H_2O	0.23	0.26	0.32	0.33
9"	0.21	0.30	0.27	0.33
18"	0.24	0.36	0.32	0.31
27"	0.28	0.37	0.33	0.32
36"	0.27	0.38	0.31	0.29

phosphorus increased with time, from season 1 to season 5 in the Asquith soil. The effect in the Oxbow soil was not the same as the percentage phosphorus remained at the same level at the lower irrigation treatments and decreased at the higher irrigation treatments. Similarly with potassium the averages of percentage potassium in the plant dry matter presented in Table 9, showed that there was an increase in the percentage potassium in the plant dry matter in the Asquith soil, while the Oxbow more or less remained at the same level or perhaps showed a slight increase. Similarly, boron levels showed a slight increase but levels were still below that concentration considered abnormal (Gupta and Stewart, 1975). In general, it can be said that the quality of the forage was improved by sewage effluent irrigation and there was no evidence from the analysis of the major nutrients that any toxic accumulation of elements had occurred (Table 10).

Table 9. Quality of forage: The percent K in plant dry matter grown under different sewage effluent irrigation treatments.

Treatment	Season 1		Season 5	
	Asquith	Oxbow	Asquith	Oxbow
H_2O	2.97	3.15	3.25	3.63
9"	2.93	3.04	3.69	3.38
18"	2.89	3.28	3.69	3.69
27"	2.99	3.21	4.50	3.75
36"	2.85	3.00	3.13	3.25

Table 10. Quality of forage: Boron concentrations (µg/g) in plant dry matter at the end of the 5th season as influenced by sewage effluent irrigation treatments.

Treatment	Asquith		Oxbow	
	Cut 1	Cut 2	Cut 1	Cut 2
H_2O	9	16	9	17
9"	21	21	11	12
18"	18	21	13	17
27"	22	15	17	14
36"	23	23	18	28

Soil Analysis

At the end of the fifth season the soil columns were analyzed for available nutrients and a summary statement (Table 11) should be given now.

Table 11. Soil Analysis Summary.

NO_3-N: Asquith soil at end of 5th season
- all treatments low, less than 8 µg NO_3-N/24" (total)

Oxbow soil at end of 5th season
- some build-up in NO_3-N but less than 12 µg NO_3-N/24" (total)

$NaHCO_3$-extractable P: (μg P/g) increases with treatment (5th season)

Soil Depth	H_2O	9"	18"	27"	36"	Initial
			Asquith			
0-6"	7.0	9.5	13.0	16.3	16.5	12.5
6-12"	5.0	5.0	7.0	7.8	8.7	5.0
12-18"	4.5	3.3	5.0	4.8	6.0	5.0
18-24"	3.0	3.3	4.0	4.3	5.3	5.0
			Oxbow			
0-6"	8.0	8.8	12.3	15.0	15.3	7.0
6-12"	3.5	4.0	6.3	8.0	7.5	2.0
12-18"	1.5	2.2	5.0	4.8	5.0	1.0
18-24"	1.0	1.2	3.8	3.8	3.5	1.0

$NaHCO_3$-extractable K: (μg K/g) was high in both soils originally and decreases slowly with time. Still high on all treatments at the end of 5 seasons.

NH_4OAc-extractable B: (μg B/g soil)

Soil Depth	H_2O	9"	18"	27"	36"
			Asquith		
0-6"	0.22	0.50	0.76	0.90	0.86
6-12"	0.24	0.50	0.92	1.08	1.12
12-18"	0.24	0.46	0.84	1.16	1.36
18-24"	0.36	0.36	0.21	0.70	1.06
			Oxbow		
0-6"	1.22	1.69	2.56	3.28	3.52
6-12"	1.48	0.84	1.88	2.74	2.80
12-18"	1.99	1.44	1.86	2.40	2.38
18-24"	2.33	1.48	1.80	1.96	1.86

NH_4OAc levels less than 0.35 μg B/g soil have been reported to be deficient in available boron (Gupta and Stewart, 1975). Levels greater than 10 μg B/g soil may be toxic.

Nitrate Nitrogen

In the Asquith soil at the end of the fifth season all treatments tested low in nitrate nitrogen with less than 8 ug/g of nitrogen in the top 60 cm. The same trend was found in the Oxbow soil, where at the end of the fifth season there was a slight build-up in nitrate nitrogen but was still less than 12 ug of nitrate nitrogen in the top 60 cm. These statements show that despite the fact that a nitrogen balance of inputs and outputs into the soil showed considerable accumulation of nitrogen in the soil (Table 12), this was not occurring in the nitrate nitrogen form. Further nitrogen

Table 12. Nitrogen balance over five seasons in kg N/ha.

In (Fert. + Sewage)	Out (Plant + Leaching)	Δ
Asquith (initial NO_3-N to 24" ≈ 19 kg N/ha)		
81	102	-21
476	242	234
869	422	447
2355	611	644
1378	633	745
Oxbow (initial NO_3-N ≈ 100 kg N/ha)		
0	79	-79
395	219	176
788	424	364
1174	543	631
1287	615	672

(Note: Very little loss of N by leaching from the profile. No measure of denitrification (fert. N 10-20% of applied N).

analyses presented in Table 13 which showed the percentage of total nitrogen in the soil at the end of the fifth season showed that there was no significant difference between the dryland treatment which had simply received the equivalent of precipitation and the treatment that had received 36" of sewage effluent, and the same applied to the Asquith soil. There was considerable variation between samples illustrating the difficulty of obtaining accurate sampling from these columns.

This data means that as the nitrogen balance obtained by measuring all the nitrogen inputs into the soil and measuring the nitrogen outputs in leachates and in plant material showed that there should be a considerable accumulation of nitrogen in the soil, and that this

Table 13. Total N (% N) in the soils after five seasons of irrigation with sewage effluent.

Soil Depth (cm)	Dryland	9"	18"	27"	36"
	$\overline{X}$ S.D.	$\overline{X}$ S.D.	$\overline{X}$ S.D.	$\overline{X}$ S.D.	$\overline{X}$ S.D.
			Oxbow		
0-15	0.3375±0.0714	0.3331±0.0464	0.3561±0.0407	0.3495±0.0291	0.3593±0.0234
15-30	0.1650±0.0057	0.1348±0.0259	0.1702±0.0366	0.2115±0.0292	0.1797±0.0256
30-45	0.0610±0.0000	0.0620±0.0147	0.0758±0.0147	0.0735±0.0064	0.0588±0.0100
45-60	0.0305±0.0021	0.0357±0.0126	0.0417±0.0124	0.0450±0.0103	0.0365±0.0085
			Asquith		
0-15	0.0785±0.006	0.0930±0.013	0.0823±0.004	0.0828±0.005	0.0858±0.005
15-30	0.0910±0.0011	0.0852±0.009	0.0825±0.009	0.0875±0.003	0.0828±0.012
30-45	0.0590±0.0028	0.0545±0.006	0.0540±0.003	0.0543±0.007	0.0505±0.005
45-60	0.0375±0.0021	0.0385±0.003	0.0393±0.003	0.0358±0.003	0.0375±0.003

was not found in the percentage of total nitrogen measurements that nitrogen losses must have occurred to the atmosphere. King (1973) found similar results with losses of 21 to 36% of surface applied N in liquid sewage sludge being lost to the atmosphere. Ukrainetz pointed out that in fertilizer experiments on the semi-arid prairies under irrigation that there was a loss between 10 to 20% of the applied nitrogen, presumably by volatilization or by demineralization. This process must also have occurred under the conditions of this experiment and also there is a chance that the soil surface would have acted as a filter for a large amount of the organic nitrogen which may not have been adequately measured in the sampling and mixing technique.

The available phosphate data as assessed by the $NaHCO_3$-extractable P showed that in both soils there was a gradual build-up in the available phosphorus status. Obviously more phosphate was being applied than the plant was using. This can be determined from a phosphate balance. At the same time the residual phosphate was remaining in a readily available form and will be available to plants in subsequent growth seasons. The amount of extractable potassium in the soil was found to decrease slowly with time. However, at the beginning of the experiment, extractable potassium level ($NaHCO_3$-extractable K) was classified as extremely high, and it would still be classified as high on all treatments at the end of five seasons.

The amounts of extractable boron in the soil were similarly found to increase and analyses taken at the end of the fifth season on the Asquith soil showed that in fact the irrigation effluent had increased the extractable levels by fourfold. The original levels in the soil were low and the levels at the end of the fourth season were still one-tenth to one-eighth of the levels that have been shown to be toxic in soils. It would appear that this presented no danger to the soil quality. However, this is one of the factors that would have to be monitored carefully with time as the boron level of the sewage does alter from time to time.

Summary

This work is shown that the application of sewage effluent irrigation to Asquith and Oxbow soils at irrigation rates of up to 36" of sewage effluent per year, will produce increased yields of bromegrass and that the quality of this bromegrass will not in any way be affected by the sewage effluent except perhaps to increase its quality. This laboratory study would need to be confirmed with some replicated tests in the field, as it was not possible to exactly simulate environmental field conditions in the greenhouse. However, this preliminary

work shows that as far as nutrients are concerned the application of sewage effluent (of the same composition as the Moose Jaw effluent tested in the study) would be beneficial to most soils.

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